LA-UR-80-2340

CONF-801016--6

TITLE: PASSIVE SOLAR DESIGN CALCULATIONS WITH THE DOE-2 COMPUTER PROGRAM

AUTHOR(S): J. F. Kerrisk, WX-4
J. E. Moore, WX-4
N. M. Schnurr, WX-4
B. D. Hunn, WX-4

MASTER

SUBMITTED TO: For presentation at the Fifth National Passive Solar Conference, Amherst, Massachusetts, October 19-26, 1980.

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

Form No. 836 R3
St. No. 2629
12/78

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

PASSIVE-SOLAR DESIGN CALCULATIONS WITH THE DOE-2 COMPUTER PROGRAM

J. F. Kerrisk
J. F. Moore
N. M. Schnurr
B. D. Hunn

Los Alamos Scientific Laboratory
Los Alamos, NM 87545

ABSTRACT

The DOE-2 computer program has been modified to improve modeling of passive-solar buildings by the addition of the custom weighting-factor method. This paper describes the thermal-load and air-temperature calculation procedure in DOE-2. Assumptions inherent in the use of American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) precalculated and the custom weighting factors are discussed. Calculated results from DOE-2 are compared with measured heat-extraction rates and air temperatures for four buildings. These comparisons indicate that DOE-2 can accurately model direct-gain passive buildings and can treat night-ventilative cooling and water walls in an approximate manner.

1. INTRODUCTION

The DOE-2 computer program (1) is used to perform building energy analysis calculations, primarily for commercial buildings. It is one of the analytical tools that can be employed to demonstrate compliance with the proposed federal Building Energy Performance Standards (BEPS) for new buildings. Air temperatures and heat-extraction rates are calculated by the weighting-factor method, which generally follows the recommendations of ASHRAE (2). Earlier versions of DOE-2 contained three sets of precalculated weighting factors, applicable to light, medium, and heavy construction. Because these weighting factors were derived from conventional-building designs, they were unable to describe the thermal behavior of direct-gain, passive-solar buildings (3). A custom weighting-factor calculation technique has been implemented in DOE-2.1, the latest version of DOE-2. Using this method, weighting factors can be calculated specifically for most rooms. These custom weighting factors provide an accurate description of the thermal behavior of direct-gain passive buildings.

An important part of the extension of DOE-2 capabilities has been a comparison between calculated and measured values of air temperatures and heat-extraction rates for a number of test buildings. Comparisons with data from the direct-gain test cell at the Los Alamos Scientific Laboratory (LASL) have been reported previously (4). Recent comparisons have been made with data from two National Bureau of Standards (NBS) test buildings, a direct-gain, passive-solar residence in Santa Fe, New Mexico, and a direct-gain, passive-solar office and warehouse with a water wall in Pecos, New Mexico. These comparisons have verified that DOE-2 can accurately model direct-gain, passive-solar buildings and can account for night-ventilative cooling and water walls in an approximate manner.

This paper is divided into two major sections. The first describes the method used to calculate air temperatures and heat-extraction rates in DOE-2. Assumptions inherent in the precalculated weighting factors and the new custom weighting factors are discussed, and the importance of a design tool like DOE-2 for commercial buildings is mentioned. The second section of this paper discusses the comparisons between measured data from various test buildings and DOE-2.1 results.

2. THE DOE-2 METHOD OF CALCULATION

The DOE-2 computer program employs weighting factors for the calculation of thermal loads and air temperatures. The weighting-factor technique, first introduced by Mitalas and Stephenson (5), is one of many methods that has been used or proposed for building energy analysis. It represents a compromise between simpler methods, such as steady-state calculations that ignore the ability of building mass to store energy, and more complex methods, such as detailed energy-balance calculations. With the weighting-factor method, an hourly thermal-load calculation is performed based on a physical description of the building and that hour's ambient weather conditions (air temperature, solar radiation, wind velocity, etc.). These loads are used, along with the characteristics and availability of heating and cooling systems for the building, to calculate air temperatures and heat-extraction or addition rates.

The information of primary interest to a building designer is the heat-extraction (or addition) rate and air temperature of a room or building zone for a given set of conditions. DOE-2 provides these data by a two-step process. In the first step, the air temperature of the zone is assumed to be fixed at some reference value. Instantaneous heat gains or losses (the rate at which heat enters or leaves the zone at a given instant) are calculated on the basis of this constant temperature. Various types of heat gains, such as solar radiation entering windows or energy from lighting within the room, are considered. A cooling load for the zone, defined as the rate at which energy must be removed from the zone to maintain the air temperature fixed at its reference value, is calculated for each type of instantaneous heat gain. (Heating loads and heat losses are merely negative cooling loads and heat gains.) The cooling load from a particular source, such as solar radiation entering through windows, differs from the instantaneous heat gain because some of the radiation can be absorbed by walls or furniture and stored for later release to the air. Heat-gain weighting factors, one set for each type of heat gain considered, are employed to calculate cooling loads from the instantaneous heat gains. Qualitatively, these heat-gain weighting factors are sets of parameters that determine how much of the energy entering a room in a given hour is stored and how fast the stored energy is released during later hours. Mathematically, they are coefficients in a z-transfer function between the z-transform of the heat gain (input) and the z-transform of the cooling load (output). The type of heat gain (for example, solar radiation entering through windows as compared with energy from lights) can affect the relative amounts of energy stored. For this reason, the weighting factors for each type of heat gain are different. Similarly, the construction of a room can influence how much incoming energy is stored and how rapidly it is released. Thus different rooms can have different weighting factors. At the end of the first step, the cooling loads from the various heat gains are summed to give a total cooling load for the room.

In the second step of the calculation, the total cooling load for a room, along with data about the heating, ventilating, and air-conditioning (HVAC) system attached to the room and a set of air-temperature weighting factors, is used to calculate the actual heat-extraction (or addition) rate and air temperature. The actual heat-extraction rate differs from the cooling load because, in practice, the air temperature varies from the reference value used to calculate the cooling load or because of HVAC system characteristics. The air-temperature weighting factors are also coefficients in a z-transfer function between the z-transform of the net cooling load (cooling load as calculated less any heat extraction done by the HVAC system) and the z-transform of the deviation of the air temperature from its reference value.

Weighting factors represent an application of z-transform methods to the solution of differential equations (6). The z-transform method has been widely used for the solution of discrete systems (difference equations), particularly for sampled data. It is a counterpart of the Laplace transform as applied to continuous systems (differential equations). For building energy analysis, the z-transform method provides an approximate solution to the differential equations describing heat transfer in a building.

Two general assumptions are made with all weighting factors used in DOE-2. The first is that the process modeled can be represented by linear differential equations. This assumption is necessary because heat gains from various sources are calculated independently and summed to obtain the overall result (that is, the superposition principle is used). Therefore, nonlinear processes such as natural convection and radiation must be approximated linearly. The second assumption is that system properties that influence the weighting factors are constant (that is, they are not functions of time or temperature). This requires that items such as film coefficients and the distribution of incident radiation on surfaces be represented by average values over the time of interest. Both assumptions represent limitations to the use of weighting factors. The linearity assumption does not represent a significant limitation at this time because the processes involved, even radiation, can be linearly approximated with sufficient accuracy for most calculations. The assumption of constant properties can limit the use of weighting factors in situations where important zone properties vary during a calculation. Two examples are the distribution of solar radiation incident on the interior walls of a zone, which can vary hourly, and film coefficients, which can vary with direction of heat flow or with air velocity.

There are many assumptions inherent in the precalculated weighting factors used in DOE-2. When the user selects precalculated weighting factors, he is accepting not only the general assumptions of linearity and constant system properties, but is also accepting the entire construction of the typical rooms for the weighting-factor calculation. This includes items such as the construction and thermal properties of the walls, window area and orientation, amount and description of furniture, distribution of incoming solar radiation, radiative properties (for example, absorptivity) of the walls, interior film coefficients, and long-wavelength radiant exchange. For this reason, the precalculated weighting factors can only approximate the description of any building zone.

In contrast, custom weighting factors are calculated for a room using an actual description of the room. The method used in DOE-2 is based on the developments of Z. O. Cumali (7). Different zones in a building can use either precalculated or custom weighting factors during the same thermal-load calculation. The greatest improvement that comes with custom weighting factors is in the use of actual building data for their determination. This is particularly important for buildings that differ significantly from typical construction, such as most buildings with passive-solar features.

For most residential and passive-solar buildings, calculation of the envelope load and the solar contribution to the interior represents the entire energy analysis. However, for commercial buildings, an entire range of conditions can be encountered from buildings dominated by envelope load to those dominated by internal loads, such as lighting, people, or equipment. Also, complex HVAC systems that heat, reheat, and mix various air streams are employed. DOE-2 can model an entire commercial building from the initial thermal-load calculation, through the HVAC system simulation, and subsequently to the building plant that ultimately supplies the heating and cooling energy. The improvement of the thermal-load calculation in DOE-2 by the addition of custom weighting factors allows features such as direct-gain, passive components to be accurately modeled in commercial buildings.

3. COMPARISONS WITH MEASURED DATA

The original impetus for developing custom weighting factors came from poor agreement between air temperatures determined using precalculated weighting factors in DOE-1 and data from the direct-gain test cell at LASL (3). Later calculations using custom weighting factors were in good agreement with test-cell data (4). Additional comparisons have been made using custom weighting factors in DOE-2.1 to model the performance of various buildings.

Hourly heat-extraction rates and air temperatures have been measured for a high-mass test house built in the National Bureau of Standards (NBS) environmental chamber (8). The single-room building had 0.20-m concrete walls, a 0.3-m concrete floor, and a concrete roof, all with exterior insulation. It was driven by a varying exterior temperature simulating diurnal sol-air temperature cycles in Saudi Arabia. Figure 1 shows results of one test in which the indoor air temperature was held at approximately 24°C (75°F) from 6 p.m. to 6 a.m. by a cooling system. Measured air temperatures and sensible heat-extraction rates are compared with the NBS loads program NBSLD (9) and DOE-2 calculated results. The agreement is quite good. Figure 2 shows results from another test on the same structure in which night ventilation (14 air changes per hour) was employed from 10 p.m. to 6 a.m. The calculated air temperatures from DOE-2 are in close agreement with measured data and the NBSLD results.

Hourly heat-extraction rates have been measured by NBS for a test house located in Houston, Texas (8). The house is a conventional wood-frame structure with brick veneer and a slab-on-grade floor. Figure 3 shows results of measured heat-extraction rates compared with DOE-2 calculations. The measured data represent the range observed for a three-day period with almost identical weather conditions while the interior air temperature was controlled at 24.5-25.5°C (76-78°F). Some drift above 25.5°C (78°F) was observed in the late afternoon. The DOE-2 calculated results, which represent heat-extraction rates while air temperatures were held in the 24.5-25.5°C range, are in good agreement with the measurements.

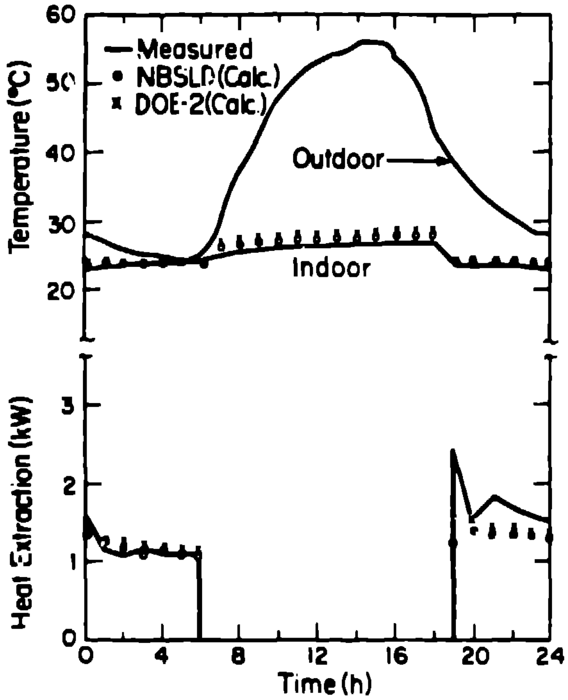

Fig. 1. Comparison of measured and calculated air temperatures and heat-extraction rates for the NBS high-mass test house.

The Dove Publications building in Pecos, New Mexico, is a 700-m² (7700-ft²) office and warehouse heated by direct gain (10). The office also contains a water-filled drum wall, which was modeled as a massive interior wall. Local weather conditions and building performance have been monitored by LASL. Figure 4 shows a

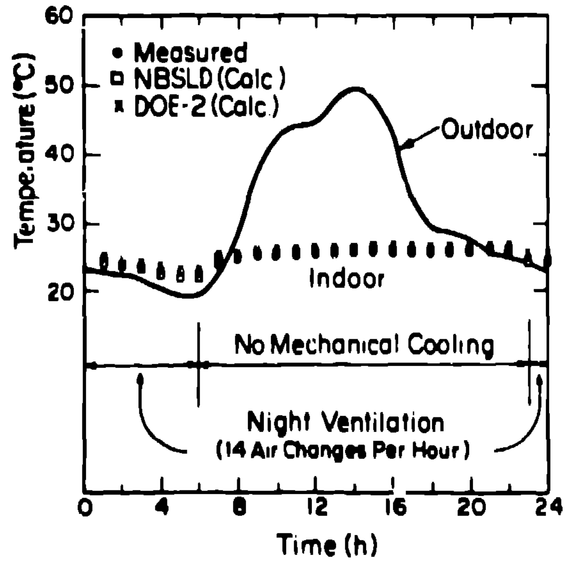

Fig. 2. Comparison of measured and calculated air temperatures for night-ventilative cooling in the NBS high-mass test house.

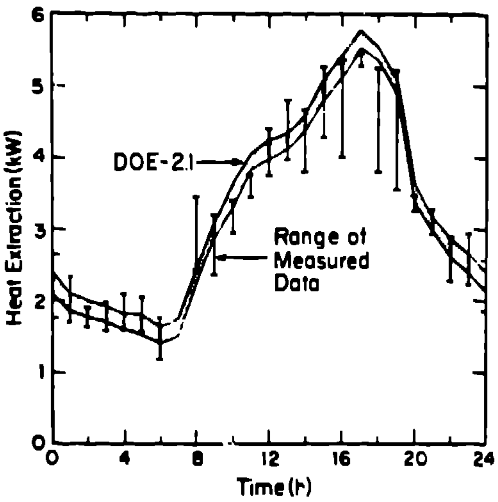

Fig. 3. Comparison of measured and calculated heat-extraction rates for the NBS Houston test house.

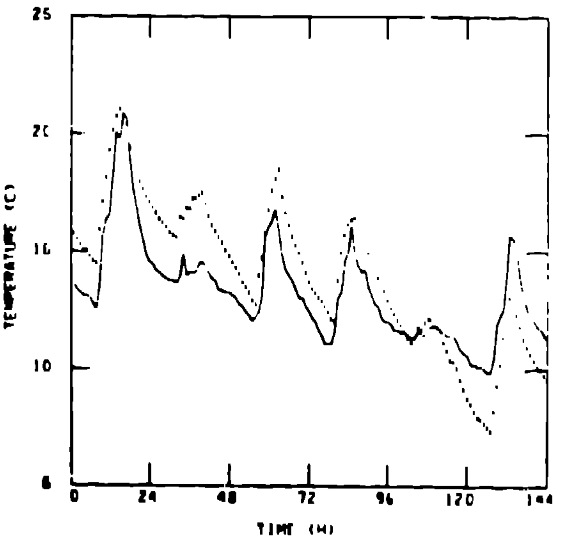

Fig. 4. Comparison between measured (solid line) and calculated (+) air temperatures for the Dove Publications building, February 10-15, 1980.

comparison between measured and calculated air temperatures in the 500-m^2 (5500-ft^2) warehouse for February 10-15, 1980. The agreement is generally good. A similar comparison for the office temperatures is not quite as good; differences up to 4°C were observed. The presence of the water wall in the office may have contributed to the differences; however, it was more likely caused by manual control of vents between the water wall and the office space that cannot now be modeled in DOE-2.

A direct-gain, single-family residence in Santa Fe, New Mexico, the Ralph Williamson house (10), has also been monitored by LASL. The 120-m^2 (1270-ft^2) building is adobe construction with exterior insulation, ground-floor and clerestory windows, and a slab-on-grade floor. Figure 5 shows a comparison between measured globe temperatures and air temperatures calculated by DOE-2 for January 18-22, 1980. Although air temperatures and globe temperatures cannot be directly compared, they are generally close except, as expected, under high-radiation conditions (midday). Comparisons for a second five-day period later in January are not as close as Fig. 5. However, high ambient temperatures and clear days probably led to an uncertain increase in ventilation from open windows during this period (11).

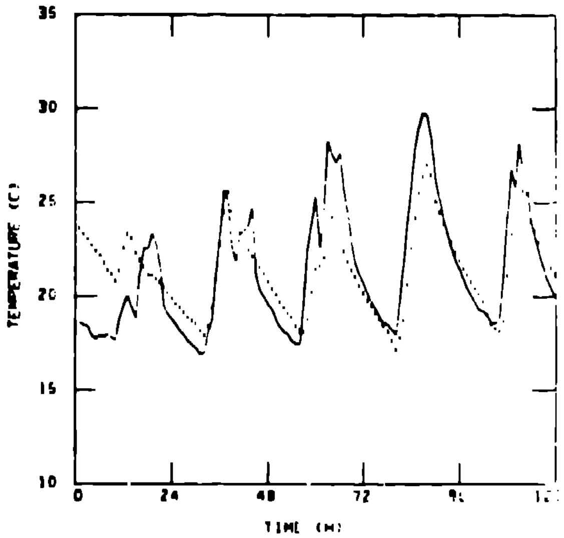

Fig. 5. Comparison between measured globe temperatures (solid line) and calculated air temperatures (+) for the Williamson house, January 18-22, 1980.

4. CONCLUSIONS

The DOE-2 computer program can now use custom weighting factors to calculate thermal loads and air temperatures in buildings. Although the weighting-factor method has certain limitations, comparisons between DOE-2.1 calculations and measured data indicate that direct-gain, passive buildings can be accurately modeled and that night-ventilative cooling and water walls can be treated in an approximate manner.

5. ACKNOWLEDGMENTS

This work was sponsored by the US Department of Energy, Office of the Assistant Secretary for Conservation and Solar Energy. The measured data for the Dove Publications building and the Williamson house were collected by LASL Group Q-11.

6. REFERENCES

(1) DOE-2 Reference Manual (Version 2.1), York, D. A., and Tucker, E. F. (Eds.), Los Alamos Scientific Laboratory (March 1980).

(2) ASHRAE, Handbook of Fundamentals (1977).

(3) Hunn, B. D., Schnurr, N. M., Peterson, J. L., Kerrisk, J. F., and Moore, J. E., "Applications of DOE-1 to Passive Solar Heating of Commercial Buildings: Preliminary Results," proceedings of the Third National Passive Solar Conference, San Jose, California, January 11-13, 1979.

(4) Schnurr, N. M., Kerrisk, J. F., Moore, J. E., Hunn, B. D., and Cumali, Z. O., "Applications of DOE-2 to Direct-Gain Passive Solar Systems: Implementation of a Weighting-Factor Calculative Technique," proceedings of the 4th National Passive Solar Conference, Kansas City, Missouri, October 3-5, 1979.

(5) Mitalas, G. P. and Stephenson, D. G., "Room Thermal Response Factors," ASHRAE Transactions, 73, Part 1 (1967).

(6) Jury, E. I., Theory and Application of the z-Transform Method, John Wiley and Sons, Inc., New York (1964).

(7) Cumali, Z. O., Sullivan, R., and Sezgen, O., "Passive Solar Calculation Methods," interim report for Contract EM-78-C-01-5221, Consultants Computation Bureau, 2930 Lakeshore Avenue, Oakland, CA 94610.

(8) Kusuda, T., National Bureau of Standards, private communication, January 1980.

(9) Kusuda, T., "NBSLD, Computer Program for Heating and Cooling Loads in Buildings," National Bureau of Standards report NBSIR 74-574 (November 1974).

(10) "Passive Solar Buildings," Sandia National Laboratories report SAND 79-0824 (July 1979).

(11) Williamson, Ralph, Santa Fe, New Mexico, private communication, July 1980.